IEEE Vehicular Radar Standards Subcommittee
February 28, 1996
Boulder, CO

Vehicular Radar and Radio Astronomy

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Abstract The third harmonic of the 76-77 GHz vehicular radar band falls within the 217-231 GHz band allocated to passive services. This band is one of the most important for radio astronomy observations. Spurious emission limits must be extended above 200 GHz in order to protect the radio astronomy service from harmful interference. Based on harmful interference thresholds for radio astronomy observations at frequencies above 200 GHz, we suggest a vehicular radar spurious emission limit of 2 pW/cm^2 measured at a distance of 3 m. Antenna beam size standards for vehicular radars are not sufficient for protection of the radio astronomy service since these standards only apply at the fundamental emission frequency of 76-77 GHz.

Astronomers are concerned about the interference threat from vehicular radars since hundreds of millions of the devices will eventually be in use.

1. Introduction

The Radio Astronomy service makes extensive use of the millimeter wave radio band. Molecules of astrophysical importance produce narrow-band (spectral line) emission and absorption at specific frequencies which are determined by fundamental physical properties of the molecules. In addition to spectral line emission, continuum (broad-band) emission is observed at millimeter wavelengths from a variety of astrophysically important processes.

One of the most important millimeter wave radio astronomy bands is 217-231 GHz. This band is allocated for exclusive use of passive (non-transmitting) radio services. Within this band fall several spectral lines arising from various isotopes of the carbon monoxide (CO) molecule. The emission and absorption of radiation by CO are important because they allow the determination of the distribution of hydrogen (H_2) molecules in the universe. (Although H_2 is the most prevalent molecule in the universe, the negligible level of emission which occurs from H_2 under typical interstellar conditions is impossible to detect). Resonant frequencies of the CO spectral lines are 219.56, 220.40, and 230.54 GHz, but due to the Doppler effect, the lines are observed at a continuous range of frequencies throughout the 217-231 GHz band, and outside of this band. Red-shifted CO lines have been observed well below 200 GHz.

Many other astrophysically important molecules are observed in the 217-231 GHz band. Surveys of the band have shown it to be particularly rich in simple molecules as well as complex organic species. These molecules trace the evolution of cosmic material from an initially diffuse state to the dense condensations from which stars form.

The 217-231 GHz band is also important for continuum observations of the cosmic background radiation--the weak, broad-band, and pervasive electromagnetic noise remaining from the origin of the universe (the “Big Bang”). The peak of the background radiation occurs near 160 GHz. The relatively nearby 217-231 GHz passive allocation is important for observations of the distribution of the background radiation, which ultimately are used to test theories of the origin of the cosmos.

Continuum observations from a variety of other objects, including ionized clouds in interstellar space, are also made in the 217-231 GHz band. Extremely sensitive continuum observations in the band are proving to be a key to determining the particulate content of the very dense clouds from which stars form. These particles, in the form of icy dust grains, are probably the reservoir from which comets form and from which the atmospheres, oceans, and ice mantles of planets eventually arise.

U.S. millimeter wave radio observatories are operated by private (academic) institutions and by Federally funded agencies. The observatory sites are scattered around the country and are situated in a variety of terrains (mountain-tops, valleys, and lower altitude flat sites). The National Radio Astronomy Observatory is presently designing the Millimeter Wave Array (MMA), a major millimeter wavelength interferometric observatory. A site for the MMA has not yet been finalized. Internationally, there are active millimeter wave radio observatories in Europe, South America, India, Australia, Asia, and Antarctica.

2. Interference Calculations

The FCC has adopted service rules to allow vehicular radar operation in the 46.7-46.9 and 76-77 GHz bands. The third harmonic of the 76-77 GHz allocation is 228-231 GHz, which falls entirely within the 217-231 GHz exclusive passive allocation. For analysis of potential interference to the radio astronomy service from vehicular radars, the following characteristics of the 76-77 GHz radars are assumed: FMCW modulation, swept over 100 MHz in ~2 ms, instantaneous bandwidth of ~1 MHz, 100% duty cycle.

The harmful interference limits for the radio astronomy service are derived in ITU/CCIR Recommendation ITU-R RA 769 (1992). The harmful interference limit has been standardized as the received emission level that will produce a 10% gain in root-mean-square system noise fluctuations during an integration of 2000 s duration when received in the 0 dB sidelobe of the telescope. The harmful level depends upon observing frequency and mode. In the 220 GHz band, the harmful level for spectral line observations is -133 dB(W/m^2) received across an assumed spectral line channel bandwidth of 2.5 MHz, which equates to a spectral power flux density of -197 dB(W/m^2/Hz). For continuum observations, the harmful interference level is -114 dB(W/m^2) across the 14 GHz allocation for the 230 GHz radio astronomy band, which equates to a spectral power flux density of -215 dB(W/m^2/Hz).

Because the sweep time of the vehicular radars is much less than a typical radio astronomy integration period (at millimeter wavelengths), the relevant bandwidth for spectral flux power density calculations, in the case of interference to spectral line observations, is based on the full sweep bandwidth of the FMCW signal, rather than the instantaneous bandwidth. At the third harmonic, the full sweep bandwidth is 300 MHz.

If the atmospheric attenuation rate is α dB/km, the vehicular radar is at a distance D km, and the spurious emission limit measured at a distance of 3 m is S_{3m} dB(W/m^2), then the received spectral flux density F dB(W/m^2/Hz) is

$$F = S_{3m} - 10 \log (300 \times 10^6 \text{ Hz}) - 20 \log (D/0.003) - \alpha D.$$

Alternatively, if the maximum spectral flux density at a distance D is specified, then the required spurious emission limit is given by

$$S_{3m} = F + 10 \log (300 \times 10^6 \text{ Hz}) + 20 \log (D/0.003) + \alpha D.$$

Radio astronomy observatories typically have control over access to a distance of approximately D = 1 km from the telescopes. This protection is necessary to avoid interference from automobile spark plugs and other uncontrolled RFI sources. The atmospheric attenuation rate, in the absence of precipitation, ranges from approximately 5 dB/km at sea level under high humidity conditions to approximately 0.05 dB/km at a dry, high-altitude site typical of millimeter wave observatories. Observations at 230 GHz are usually made during periods of low atmospheric attenuation. For a radio astronomy site at a relatively low altitude of 1.2 km, and with a 2.5 gm/m^3 atmospheric water vapor density, we have computed that the attenuation level is approximately 0.4 dB/km. Using the radio astronomy spectral line harmful interference level of F = -197 dB(W/m^2/Hz), the corresponding vehicular radar spurious emission limit at 3 m is

$$S_{3m} \text{ (spectral line)} = -197 \text{ dB(W/m^2/Hz)} + 84.8 \text{ dB(Hz)} + 50.5 \text{ dB} + 0.4 \text{ dB} = -61.3 \text{ dB(W/m^2)} = 74 \text{ pW/cm^2}.$$

(Note change of units to pW/cm^2, in conformance with the FCC NPRM on emission standards).

The computation for the continuum harmful interference case assumes that the entire power output of the radar falls within the 14 GHz radio astronomy band. In that case, the received power density at a distance of 1 km is

$$F = S_{3m} - 10 \log (14 \times 10^9 \text{ Hz}) - 20 \log (D/0.003) - \alpha D.$$

For a harmful interference level of F = -215 dB(W/m^2/Hz), the allowed power output of the radar measured at 3 m distance is

$$S_{3m} \text{ (continuum)} = -215 \text{ dB(W/m^2/Hz)} + 101.5 \text{ dB(Hz)} + 50.5 \text{ dB} + 0.4 \text{dB} = -62.6 \text{ dB(W/m^2)} = 55 \text{ pW/cm^2}.$$

The current FCC NPRM on spurious emission standards for vehicular radars suggests a spurious emission standard of S_{3m} = 1000 pW/cm^2 above 200 GHz. This standard is based on informal measurements of third harmonic emissions from a prototype vehicular radar. However, our understanding is that the measurements were inconclusive: only a single measurement out of three yielded the 1000 pW/cm^2 level; another measurement of the same radar yielded a spurious emission level of 0.04 pW/cm^2, and a measurement of a radar of somewhat different design yielded no detectable third harmonic emissions down to a level of approximately 0.0004 pW/cm^2.

The NPRM suggests applying spurious emission standards to frequencies up to 231 GHz. Emission standards in the initial NPRM applied only below 200 GHz, and no standards were suggested above 200 GHz. Below 200 GHz, the current NPRM proposes spurious emission standards of 600 pW/cm^2 for 76-77 GHz radars, and a substantially smaller value of 2 pW/cm^2 for 46.7-46.9 GHz radars (all power densities measured at 3 m distance).

The proposed standard is substantially greater than the harmful interference limits at a distance of 1 km, as computed above. Working backward, the 1000 pW/cm^2 proposed limit requires a single vehicular radar to be at a distance of nearly 4 km in order to meet the continuum harmful interference limit.

Mitigating circumstances include the effect of terrain shielding, since many (but not all) millimeter wave observatories are located in mountainous terrain. Also, the high gain of millimeter wave radio antennas make it possible that the interfering signals will enter at less than the 0 dB sidelobe level. Conversely, these calculations take into account the radiation from only a single vehicular radar, while the number of vehicles in the vicinity of the observatory may be substantially greater than one. Also, the atmospheric absorption coefficient will be less than 0.4 dB/km at many millimeter wave observatory sites, since they are generally located at high altitudes.

3. Radio Astronomy Concerns

The radio astronomy community is seriously concerned with the effects of spurious emissions from vehicular radars on observations in the 217-231 GHz frequency band. The level of third harmonic emission limits proposed by the FCC indicates that a coordination zone nearly 4 km in radius would be needed to meet harmful interference thresholds for a single radar. Most observatories are not able to regulate vehicular traffic in such a large surrounding area; at least one is located in direct line of sight to a highway less than 2 km distant, and others have direct lines of sight to roads at lower elevations.

Maintenance of spurious emission limits after the initial production of the radar units is another concern. Since many automobiles are operated with improperly functioning (or poorly maintained) headlights, tires, windshield wipers, seatbelts, and other safety items, it is reasonable to expect that many vehicles, due to minor collision damage or improper maintenance, will be operating with radar systems that do not meet spurious emission standards. While this is beyond the control of the radar manufacturers, it should be taken into account when specifying initial spurious emission limits. Besides being an interference problem, an improperly functioning millimeter wave radar system also poses a health hazard.

Radio astronomers do not believe that specifying limits on beam widths for vehicular radars is a viable solution to the interference threat, since such limits will obviously apply only at the fundamental frequency of 76-77 GHz. Antenna beam performance at the third harmonic will be difficult to predict. Furthermore, since radars will operate while the vehicles are traveling uphill, downhill, and around curves, specifying beam width limits does not keep the radar beams from illuminating off-road objects, such as a radio telescope.

In order to minimize the interference potential, the radio astronomy community would like to see vehicular radar spurious emission standards set such that the harmful interference threshold is not exceeded due to the operation of motor vehicles beyond a distance of 1 km from a radio telescope. The third harmonic limit of 55 pW/cm^2 at 3 m, as derived in the previous section, applies to only a single vehicular radar. We propose that a third harmonic spurious emission standard of 2 pW/cm^2, measured at a distance of 3 m, be invoked. This limit conforms to the standard below 200 GHz that has been adopted for 46 GHz vehicular radars, which suggests that this level of harmonic suppression is achievable. Further, this limit helps protect radio telescopes under the likely circumstance of having more than one vehicle operating in the vicinity of the observatory but outside the 1 km protection zone, and also helps protect radio astronomy observations in the event of an improperly maintained radar functioning in the vicinity of a radio telescope.

The proposed limit of 2 pW/cm^2 is approximately 75 dB below the 3 m power limit of 60 μW/cm^2 at the fundamental frequency, a suppression level which radio astronomy millimeter wave engineers believe can be achieved (again, spurious emission limits below 200 GHz adopted for 46 GHz vehicular radars are 75 dB down from the fundamental, with apparently no objection from the manufacturers of those radars). The radio astronomy community believes that a 2 pW/cm^2 limit should apply to spurious emissions at all frequencies above 200 GHz, rather than just those that fall in the 217-231 GHz passive band, since spectral line observations of many astrophysically important molecules as well as CO red-shifted to frequencies below 217 GHz are often necessary.

Some radar manufacturers have expressed concern over the availability of test equipment sufficiently sensitive above 200 GHz for spurious emissions testing at the 2 pW/cm^2 level. It is our understanding that at least one company produces such equipment. Further, perhaps vehicular radar manufacturers should design and market their own test equipment, since a large industry for this equipment will apparently exist in the near future.

The radio astronomy community would like the automobile industry to consider including on/off switches with the vehicular radar systems. In this fashion, radio observatories could place signs along nearby roads requesting that vehicular radars be turned off, to further protect radio astronomy observations. It seems to us that the on/off capability may be required in any event to assure safety when passing radio-controlled blasting zones.

Finally, the radio astronomy community is concerned about the eventual proliferation of vehicular radar systems. Considering that there are nearly 200 million registered motor vehicles in the U.S. alone (1994 figure), the potential for interference to radio astronomy observations from spurious vehicular radar emissions is significant. Indeed, it will lead to a situation analogous to that experienced by many formerly important optical astronomy observatories whose activities are now severely curtailed due to light pollution from nearby cities.